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Engineering**www.elsevier.com/locate/procedia11th International Conference on Modern Building Materials, Structures and Techniques,
MBMST 2013**Selection of Efficient Retrofit Scenarios for Public Buildings**Matej Kušar^a, Maruška Šubic Kovač^b, Jana Šelih^{c,*}^{a,b,c}Faculty of Civil and Geodetic Engineering, University of Ljubljana, Jamova 2, 1000 Ljubljana, Slovenia**Abstract**

Over the past two decades, the importance of the management of existing buildings is continuously increasing with time. Refurbishment of buildings requires execution of various measures that have to be carefully chosen, as selection of a set of refurbishment actions demands that the goals of contemporary sustainable development are achieved. Therefore, a rational decision model is required to select a set of refurbishment measures for a building that results in largest total benefit to cost ratio. This ratio has to be calculated on the basis of several relevant criteria. The basic criteria are identified in this paper as life cycle costs of the building and its structural safety. In Slovenia, an important component of the latter criterion is earthquake resistance, while life cycle costs are predominantly linked to energy consumption of the building. Development and justification of the multi-criteria decision model is presented in the next step. The use of the model is limited to buildings in public ownership. The model takes into the account the fact that refurbishment measures carried out in the present result in reduced operation and maintenance costs over the remaining service life. Life cycle costs reduced due to building energy retrofit have a major impact upon the environmental and economic performance of the building during its operation, while the earthquake resistance improvement (since it decreases the probability of lost human lives) has primarily social impact.

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Keywords: Building refurbishment; public buildings; multi-criteria decision model; earthquake resistance; energy rehabilitation; life cycle costs.**Nomenclature**

C_i	sum of maintenance and operation costs and potential refurbishment costs in case of earthquake damage in year i , $i = 1, \dots, T$ (EUR)
d	selected discount rate (-)
INV	cost of the envisaged set of refurbishment actions (EUR)
NPV	net present value of a selected refurbishment scenario (EUR)
NPV_{LCC}	net present value (of the refurbishment scenario / set of refurbishment actions) (EUR)
NPV_S	net present value of the total seismic upgrade costs, and costs of eventual earthquake damage (EUR)
NPV_{res}	net present value of residual value of material and equipment (at the end of the time interval, T) (EUR)
T	length of the time interval under consideration (years)
V_T	residual value of the planned investment measures (at the end of the time interval) (EUR)

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1. Introduction

Management of the building stock is constantly gaining attention, predominantly due to the large investments required to construct it and maintain it. Increasingly, especially in more developed countries, special efforts are aimed at the existing assets, as their number is continuously increasing.

The performance of any building or other structure decreases with time due to aggressive environmental conditions and different inherent factors throughout their service life. When the performance reaches the minimum acceptable level, two options are available: demolition and construction of new building complying with contemporary requirements, or refurbishment of the existing one. Following the sustainability principles applied to the built environment, where the whole life cycle of the building is taken into the account [1], it can be derived that in the majority of cases, refurbishment is preferred to demolition and replacement of the building. Dong et al [2] analyze several case studies and conclude that retrofitting a building results in lower water pollution, solid waste generation and resource use. On the other side, it is shown that replacement can, in some cases, result in lower life cycle energy and other factors associated with building operation. Some authors [3-6] focus to energy efficiency improvement of the building only, which, although important, should not be the only aspect considered in refurbishment. Asadi [7] considers various combinations of refurbishment scenarios regarding different building components in order to arrive to the optimum retrofit solution. Studies reported in [8], [9] include also criteria such as life cycle cost after the refurbishment, and satisfaction level of various project stakeholders, including users. In [10], however, social aspects and urban scale measures are taken into the account as well.

Another line of research aiming at supporting the decisions regarding refurbishment is investigation of the influence of the structural condition of the building. Research in this area has been predominantly focused on the single criteria decision models, where most often, structural integrity, or in earthquake prone countries, the more specific earthquake resistance of the building was considered only, e.g. [11]. The study carried out by Bosiljkov [12] emphasizes also the importance of the systematic assessment of the condition of the structure prior to refurbishment.

Several actions are usually required to upgrade the condition of the building. As available funds are always limited, the owners have to consider very carefully their aims, and the resulting scope of refurbishment works. In order to arrive to a rational decision, the use of comprehensive decision models based on quantitative methods is highly recommended. Only then, an optimum, the most cost effective solution can be proposed for the building refurbishment.

The purpose of this paper is therefore to present the foundations and development of a multi-criteria decision model to be used to select the best refurbishment solution for a building in public ownership (e.g. public library, senior citizen home, hospital, school). This group of buildings represents a significant proportion of the total building stock in any country. Their life cycle management should be transparent and cost efficient, and decisions taken during the life cycle should be based on clear, rational grounds. Therefore, the model is adapted to specific needs of such buildings. Further, we wish to establish a simple, transparent and robust model that can be easily understood and used by the decision makers in practice.

The limitation of public ownership implies that the increase of the market value of the building after the refurbishment is carried out is irrelevant. This is due to the fact that publicly owned buildings are intended to satisfy particular needs of a targeted group of users (e.g. schools enable carrying out the educational process for the children) on a long-term basis, and therefore, in principle, they are not on the market.

The criteria to be used in the model are identified, justified, discussed and quantified. The result of the decision process is the scope and type of actions to be performed within refurbishment project.

2. Multi-criteria decision model development

When several alternative solutions are available to solve a particular problem, the multi-criteria decision models help the decision-maker to select the alternative that is the optimal (preferred), i.e. yields the largest utility, or benefit, with respect to a set of pre-defined criteria and their pre-set relative importance. The total utility is calculated from values assigned to these criteria [13-14].

It is therefore clear that careful identification and description of the criteria to be used in the analysis is its first and extremely important step.

Every building is unique due to its dimensions, shape, function, age, location and resistance to various environmental influences. These properties have a major influence upon the state of the building and consequent selection of refurbishment actions. An important element in the decision process is also the initial condition of the facility [9; 15-16]. Initial condition has to be assessed by a well-defined, systematic methodology, and carried out by a trained assessor. Within the assessment process, total energy consumption and structural integrity have to be determined, as well as condition of individual (structural and non-structural) components of the building, such as windows, facade, chimney, partition walls.... Combined

with clearly defined requirements and needs of the owner and/or user, and owners' financial limitations, it represents the baseline for further decision making regarding refurbishment.

2.1. Identification of the criteria

For public buildings, to which the proposed model is focused, their market value is irrelevant when the extent of refurbishment actions is planned. This limitation eliminates also the influence of the building location, which could be substantial if building's market value was taken into the account. From the financial point of view, therefore, the main concern is targeted to the cost of investment (large-scale) maintenance, routine maintenance and management over a pre-defined time period. In addition, capital maintenance cost-related benefits are also of interest.

In order to identify appropriate criteria by which various refurbishment scenarios will be judged, benefits gained by various refurbishment actions have to be defined. Three major types of benefits can be identified after refurbishment of a building. The first benefit is the reduced energy consumption of the building during its operation after refurbishment. In the operation phase of the building life cycle, the energy is used for heating, cooling, ventilation and other types of energy related processes. The reduced energy consumption is a result of refurbishment that includes energy rehabilitation of the building, and can be easily converted into monetary value.

The second benefit appears at the occurrence of a natural disaster, e.g. earthquake. It comes into the effect if the building is appropriately reinforced for the particular natural disaster type at the time of its occurrence. Extent of damage inflicted by a potential natural disaster and associated rehabilitation costs have to be assessed for initial and retrofitted state of the building. The benefit obtained is the building damage reduction at actual occurrence of the disaster. It is gained from the investment into the seismic strengthening of the building. In addition to the described direct damage to the building, indirect damage, such as number of days the building is out of use, the cost of temporary relocation of activities being carried out in the building to another location, etc, can also be considered. Insufficient structural resistance of a building can lead, in case of a natural disaster, also to loss of human lives. However, as estimating the (financial) value of lost human lives is impossible to determine and considered unethical [17], it is not taken into the account in the proposed decision model.

The third benefit is associated with the increased value (however not market value) of the building due to its renewal and related investment. This value refers to the monetary value of the materials and equipment built in the building only. Each building has, irrespective of its purpose, a certain value in terms of its in-built material and equipment. As the proposed model only compares different refurbishment scenarios for a single building, the total value of the initial in-built material and equipment of the building is equal for all solutions and thus irrelevant in the calculation of this benefit. The increased value (the benefit) is the monetary value of the materials and equipment built into the facility during refurbishment.

By taking into the account these values, it is ensured that the benefit/value of each material is accounted over its entire service life, not only for the time interval considered in the analysis.

From the above discussion, the following criteria can be outlined:

- a) Costs of energy refurbishment of the building, along with the benefits and costs related to regular operation and maintenance of the building;
- b) Cost and benefits related to earthquake resistance upgrading of the building;
- c) Residual value of planned refurbishment investments, at the end of the time period under consideration.

In order to be able to compare various sets of refurbishment actions, the costs and benefits must be aggregated into the final (single) result.

2.2. Multi-criteria decision model definition

The initial step of the MCDM model, as presented in Fig. 1, is the selection of the building to be analysed, followed by the assessment of the current state of the building by using a comprehensive, objective methodology. The assessment is the basis for the identification and evaluation of a set of possible refurbishment scenarios.

Once the set of solutions is specified, each solution needs to be evaluated against a set of criteria that describe, within the local context, the most critical aspects of the building. In case of Slovenia, which is an earthquake prone country with predominantly harsh climate [18], these aspects, or criteria adopted in the multi-criteria model under development, are earthquake resistance and energy efficiency of the building

2.3. Evaluation of the criteria

The values belonging to all criteria listed above must be objectively evaluated for every identified alternative solution.

The costs and the benefits are generated at different times, which means that the net present values (NPVs) of various costs and benefits have to be obtained by using the discounting technique.

The net present value of each refurbishment scenario (alternative) considered, NPV, can be written as

$$NPV = INV + \sum_{i=0}^T (C_i / (1+d)^i) + V_T / (1+d)^T \quad (1)$$

Where INV is the cost of the envisaged set of refurbishment measures, T the length of the time interval under consideration, C_i the sum of maintenance and operation costs and potential refurbishment costs in case of earthquake damage in year i ($i=1, 2, \dots, T$), V_T residual value of planned investment measures at the end of the time interval under consideration, and d the selected discount rate.

It can be seen that C_i encompasses also the potential benefits to be gained due to increased earthquake resistance of the building and due to increased thermal insulation. These benefits are to be manifested as reduced heating/cooling costs and reduced damage of the building in the case of an earthquake.

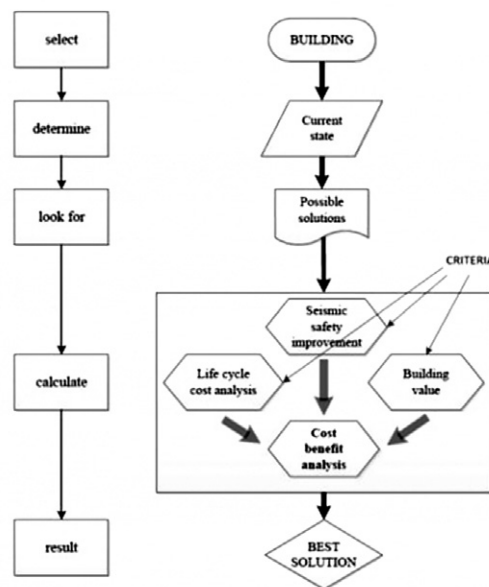


Fig. 1 Conceptual design of the multi-criteria decision model to be used in the evaluation of various refurbishment scenarios

The costs and benefits have to be determined for every year for the time interval considered in the analysis. Selection of the discount rate is therefore a crucial step significantly affecting the final results of the analysis. Social discount rate based on long-term economic growth as proposed in [19] is being employed in the proposed decision model. More explicitly, in [19], EU (DG Regions) has suggested a value of 5,5% for social discount rate for the Cohesion countries and 3,5% for other countries.

The lowest social discount rate possible should be used for the analysis of an urgent building refurbishment case. The rationale for this decision is based on the fact that this type of construction works is usually extensive and requires scaffolding, removal of separate parts of the building and severely limits the use of the building during the works' execution. It is therefore rational to carry out other works at the same time. Alternatively, the non-urgent works could be executed in the near future. A lower discount rate selected for the case analysis therefore leads to a larger proportion of economically justified non-urgent works, as the associated future benefits are higher.

If refurbishment is not urgently needed (i.e. if structural safety is adequate), the works should be carried out only if benefits associated with refurbishment works are proved to be sufficiently high. As a consequence, the selected discount rate should be higher as in the case of urgent refurbishment. The following values are therefore proposed for the discount rate employed in the analysis: 3% if the building requires urgent refurbishment; 5% if the refurbishment is not urgent and

the extent and type of refurbishment actions is still under consideration; 4% if the case under consideration is between the two limit situations presented above.

Net present value of an alternative solution, NPV, can be expressed also as a sum of partial net present values related to above defined criteria. The following expression applies:

$$NPV = NPV_{LCC} + NPV_S + NPV_{RES} \quad (2)$$

Where NPV_{LCC} is net present value of the energy rehabilitation cost and operation and management costs over the time interval considered; NPV_S net present value of the sum of seismic safety upgrade costs and costs of eventual earthquake damage; and NPV_{RES} net present value of residual value of material and equipment at the end of the time interval considered in the analysis.

Net present value, NPV, has to be determined for all identified refurbishment solutions. The methodology to be used consists of several steps. Determination of the first term, NPV_{LCC} , that describes life cycle costs, requires unambiguous classification of building's life cycle costs as proposed in [20]. The following step requires obtaining reliable data for all cost categories. Benefits related to earthquake resistance upgrading have to be determined by using probabilistic approach, and associated costs are based on the bill of quantities for listed rehabilitation works. The residual value of the total refurbishment works to be carried out can be calculated if total utility period and actual age are known for each element of the building. It is assumed that the residual value of any selected component decreases linearly from the initial value (at the time of construction) to 0 at the end of total utility period. The details of the proposed procedure are given in [21].

The solution with the highest calculated NPV is the preferred option, as it yields the most favourable cost to benefit ratio.

3. Concluding remarks

The increasing number of existing buildings requires rational and transparent decision making process when various refurbishment options for a single, or a group of buildings, are considered. The overview of the practice shows that too often, these decisions are made on the basis of subjective assessment of the building and its environment.

In order to improve this decision process, a simple multi-criteria decision model for a single building was developed. By using this model, a set of viable refurbishment scenarios can be assessed against the selected criteria, and the most suitable refurbishment scenario for a single building can be selected. Two main criteria are identified as the most relevant for a building located in earthquake-prone country, namely maintenance and operation costs and seismic resistance of the building. The paper justifies and quantifies these two criteria.

By using the proposed tool, a rational foundation for the decision regarding the type and scope of refurbishment works for a single building can be provided. In its present form, the multi-criteria decision tool is limited to buildings in public ownership. As a consequence, its use can also help to increase transparency of building refurbishment-related public procurement.

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